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Mercury and Chlorinated Hydrocarbons in Zoobenthos of Lake Päijänne, Finland

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Abstract. The average amounts of mercury, PCBs, and Σ DDT (primarily DDE), found in macrozoobenthos, on the wet basis, in Lake Päijänne, Finland, for the time period 1972–1974, were 79 ng/g, 29 ng/g, and 8 ng/g, respectively. Lindane was found in negligible amounts in only 2% of the samples examined; aldrin was present in 10% of the samples; no dieldrin was detected. Mercury and PCB concentrations varied regionally in the lake. PCB and Σ DDT concentrations were greater in the predatory bottom animals than in the herbivores or detritus feeders, and the amounts of chlorinated hydrocarbons were greater in profundal animals than in littoral animals. No significant correlation was apparent between the amount of residues found and the weight of the animal (e.g. *Anodonta*). A significant positive correlation was evident in the amounts of PCBs and Σ DDT in most of the taxonomical groups. *Spongilla lacustris* and *Anodonta piscinalis* were excellent species for monitoring purposes.

Mercury and chlorinated hydrocarbons were determined in aquatic vascular plants, plankton, sediment, zoobenthos, fish and aquatic birds which were sampled during the period of 1972–74 from Lake Päijänne, Finland (Särkkä *et al.* 1978). Our knowledge of the amounts of these contaminants in the lake are quite poor, and the aim of the present study was to examine the zoobenthos in a food chain investigation. The main problems were to find the possible annual and regional differences, bioaccumulation, differences between the quantities in the different taxonomical or in certain ecological groups as well as the correlations between the different residues. Comparisons were also made with the results of other investigations concerning the residue amounts in the zoobenthos.

Lake Päijänne receives wastes principally from three origins (Figure 1). Sulphite and sulphate pulp mill wastes come from the north in the upper part of the watercourse. The second part of the wastes is discharged into the northern part of the lake from the town of Jyväskylä via a small Lake Jyväsjärvi (station 1), and these effluents contain urban sewage in addition to the effluents from a paper mill. The third source of wastes is in the central part of the lake near station 3, which receives effluents from a sulphite pulp mill, two paper mills, and a minor amount of domestic wastes. When flowing from north to the central part, the

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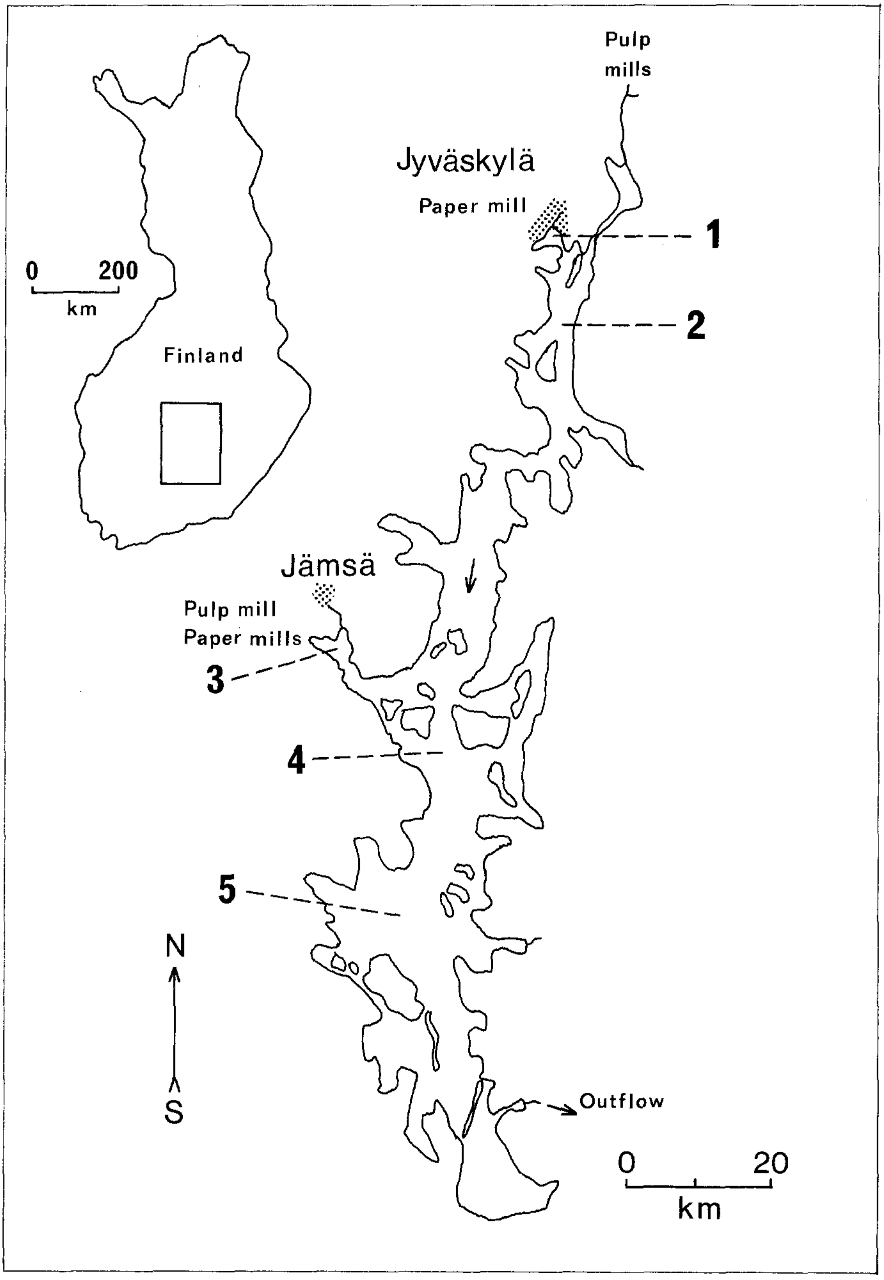

Fig. 1. Lake Päijänne and the sampling stations 1 to 5.

water becomes practically clean; another gradient can be seen from the central part (station 3) to the southern part (station 5), which is quite clean.

Mercury was used as a slimicide until 1968 in the Finnish wood processing factories. Losses into the waters as slimicides and as an impurity in caustic soda were estimated during the period 1953 to 1966 to have been 4.1 tons annually

(Häsänen 1973). Based on production figures of the wood processing industry, about 20% was discharged into Lake Päijänne annually. The use of DDT and PCB in Finland has been negligible, and the amount of DDT sold in Finland from 1953 to 1971 was 229 tons, but its use has been prohibited since 1971 (Markkula 1972). Approximately 240 tons of PCB compounds were used in Finland in 1969, (Rautapää 1972).

Methods

Total mercury analysis was made in 284 samples and chlorinated hydrocarbon analysis in 114 samples, representing the most important biomass of the macrozoobenthos. Sampling was made primarily with a quadrangular dredge from the sublittoral and with a sledge from the profundal zone. Scuba diving was employed in the sampling of *Anodonta* in addition to the dredge. A motor pump was used in the sifting and the sieve was made of stainless steel net, 0.66 × 0.66 mm. The samples were frozen in cardboard boxes.

Total mercury determinations were made by flameless atomic absorption, following the procedure of Hatch and Ott (1968) with a Coleman MAS-50 mercury analyzer. A sample of 0.5–1.0 g wet material was homogenized in an Erlenmeyer flask with 0.5 ml water and 10 ml concentrated sulphuric acid (Merck, p.a.). The flask was kept in an ice-bath. The flask was covered with a plastic film and stored at 60°C for 4 hr. After cooling, 15 ml $KMnO_4$ (6%) was added from a burette and the flask was stirred in the ice bath. The sample was diluted to 100 ml and 2 ml hydroxylamine hydrochloride (20%) and 1 ml $SnCl_2$ (40% in 5% sulphuric acid) were added and the analysis was made immediately. A stock solution of $HgCl_2$ (Merck, p.a.) was used as a standard.

The procedure for the analysis of chlorinated hydrocarbons was as follows: After liquefying the sample material, one g of sample was weighed and ground in a mortar with acid-washed sea sand (Merck) and anhydrous sodium sulphate (Merck, p.a.). The sample was transferred to a glass container and kept at room temperature for 48 hr. The fat extraction and its quantitative determination was carried out by a Soxhlet method (Hattula 1973). The solvent used was a mixture of petroleum ether, diethyl ether, acetone and n-hexane (8:2:11:5 v/v). The cleanup was carried out with one half of the fat extract by shaking with concentrated sulphuric acid and then with chromic acid (Ahling and Jensen 1970, Westöö and Noren 1970). The resulting solution was used for the aldrin, PCB and DDE determinations. The second half of the extract was purified by TLC (Hattula 1973), from which a fraction was collected for the DDD, DDT, lindane and dieldrin determinations.

A Varian Model 600 gas chromatograph with a ^3H electron capture detector was used. The column was a glass coil 1.5 m long, inside diameter 1.5 mm, filled with a mixture of 8% QF-1 and 4% SF-96 (65:35) on Chromosorb W (acid washed, silanized) 100/120 mesh. Column temperature was 180°C, injector 225°C, and detector 200°C. The quantitation was made by comparing the peak heights of the chromatograms to the chromatograms of standard PCB and organochlorine pesticide mixtures (Paasivirta *et al.* 1975).

Results

General

The largest residue was that of mercury (Table 1) followed by PCB and Σ DDT (the sum of DDE, DDD and DDT). Lindane was present only in 2 of 114 samples (in *Anodonta piscinalis* from station 2, 1 ng/g, which was the lowest measurable amount). Aldrin was found in 12 samples: station 1, *Anodonta,* 5 ng/g; station 5, in ten individuals of *Anodonta,* mean 4 ng/g and maximum 12 ng/g and in *Spongilla,* 2 ng/g. Dieldrin was not found in any of the samples examined.

Table 1. The average amounts of different residues in the zoobenthos of the different stations in Lake Päijänne, total averages and ranges, ng/g, wet weight basis. Stations given are as in Figure 1.

	Stations						
Residue	1	2	3	4	5	Mean	Range
Total mercury	83	108	31	106	55	79	0–800
PCB	63	23	21	29	21	29	0–102
DDE	11	4	5	10	7	8	0–37
DDD	0	0	0	0	0	0	0
DDT	0	1	0	0	0	0	0–5
Σ DDT	11	5	5	10	7	8	0–37
Lindane	0	0	0	0	0	0	0–1
Aldrin	0	0	0	0	1	0	0–12

Annual Differences

The differences between the materials sampled in the years 1972, 1973 and 1974 were tested from the whole material by Friedman two-way analysis by ranks (Siegel 1956). The annual amounts of mercury were about the same, but the values of PCB and Σ DDT showed a significant ($p < 5\%$) annual variation. A slight increase of PCBs and Σ DDT were noted.

The annual differences were studied within each subarea by means of the t-test. It was observed that the amounts of mercury decreased in the zoobenthos of station 1, PCB and Σ DDT increased at station 5 and Σ DDT increased at station 4.

Regional Differences

One of the primary reasons for the study was to note any possible regional differences. Both non-parametric and parametric statistical tests were used. Because of the variation of e.g. annual, taxonomical and vertical factors, too, only the highly significant regional differences were noted (Table 2).

The amounts of mercury and PCB were greatest at station 1. The regional distribution of Σ DDT was more uniform than that of Hg and PCB. The greatest regional differences were seen in Pelecypoda (consisted mainly of *Anodonta*) and Insecta (mainly Chironomidae) in which the variety of the material was also the greatest. The rather easily obtainable crustacean *Mysis relicta* showed no regional differences, nor the group Crustacea as a whole.

Differences between Taxons

Table 3 presents the amounts of the main residues in the different taxons. The quantities of mercury varied significantly ($p < 5\%$) between the taxons (Friedman two-way analysis by ranks).

Bioaccumulation within the Whole Zoobenthos

Figure 2 and Table 4 show that the amounts of PCB and Σ DDT were greater in the predatory bottom animals than in the herbivores or detritus feeders. A corresponding difference was not found in the quantities of mercury. Thus, it is apparent that the chlorinated hydrocarbons accmulate more easily than mercury in the food chain within the zoobenthos. On the other hand, this may prove that mercury has been transferred to the bottom animals directly from the water, or from the sediment or other substrates and not from the food chain.

The food-chain concentration of chlorinated hydrocarbon pesticides in the invertebrate communities was also studied by Rosenberg (1975), who showed that the results reported in the literature were not wholly reliable. This type of concentration, however, seems to exist in the zoobenthos of Lake Päijänne. The groups in the trophic levels could be divided into more numerous groups as suggested by Jernelöv and Lann (1971). When studying food-chain concentrations, it must be noted that there exists omnivorous species and changes in food habits (Rosenberg, 1975). Also, when wider taxons are studied, there may be great differences in feeding habits between the species of a certain group; and the depth and the season may affect the feeding habits and the residue concentrations.

The profundal animals contained significantly more PCB and Σ DDT than the littoral animals (Figure 2). It must be noted that the differences observed between the littoral and profundal fauna may be due to the higher fat content of

Table 2. A summarized presentation on the regional differences of the amounts of total mercury, PCB, and ΣDDT in the zoobenthos of Lake Päijänne

The regional data compared	Statistical tests	Residues having significant variations	Regions having the greatest amounts
Total regional averages (see Table 1)	t-tests	PCB	Station 1
Annual regional averages	Analysis of variance	PCB[a]	Station 1
,,	Analysis of variance	ΣDDT[a]	Station 4
Regional averages of different taxons	Friedman test	—	
,,	Analysis of variance	PCB	Station 1
,,	Analysis of variance	ΣDDT	Stations 1 and 4
Regional averages of taxonomical groups	Friedman test	—	
Regional averages of taxonomical-ecological groups mentioned in Table 4.	t-tests and analysis of variance	Hg[b]	Stations 1 and 2
,,	t-tests and analysis of variance	PCB[b]	Station 1
,,	t-tests and analysis of variance	ΣDDT[bc]	Station 1

[a] In 1973.
[b] Pelecypoka, Insecta, herbivores and littoral animals having the greatest regional differences.
[c] The analysis of variance showing no significant regional differences.

Table 3. Average amounts of total mercury, PCB and Σ DDT, ng/g, wet weight basis, in different zoobenthos taxons. S.D. = standard deviation. He = principally herbivore or detritus feeding taxon, Pd = mainly predator, Li = sampled mainly from the littoral zone, Pr = sampled mainly from the profundal zone.

	Total mercury			PCB		
No Taxon	Mean	S.D.	n	Mean	S.D.	n
1 *Spongilla lacustris* (L.)	173	311	6	5	5	6
2 *Anodonta piscinalis* Nilss.	54	49	88	25	16	64
3 Sphaeridae	32	35	5	—	—	—
4 *Sphaerium corneum* (L.)	10	15	5	—	—	—
5 *Pisidium* spp.	14	19	9	7	2	2
6 Gastropoda, miscellaneous	11	4	2	—	—	—
7 *Valvata piscinalis* (Müll.)	37	25	6	—	—	—
8 *Bithynia tentaculata* (L.)	15	13	3	—	—	—
9 *Lymnaea stagnalis* (L.)	3	—	1	—	—	—
10 *L. peregra* (Müller)	5	3	3	15	—	1
11 *Planorbarius corneus* (L.)	14	7	6	—	—	—
12 Planorbidae, miscell.	33	47	2	—	—	—
13 Oligochaeta	35	39	5	—	—	—
14 Tubificidae	161	—	1	—	—	—
15 Hirudinea	23	31	3	42	16	2
16 *Mysis relicta* Loven	46	26	9	33	17	4
17 *M. relicta*, 0+ year-old	12	4	2	45	30	2
18 *M. relicta*, 1+ year-old	58	4	2	29	6	2
19 *Asellus aquaticus* (L.)	55	111	5	—	—	—
20 *Pallasea quadrispinosa* Sars	50	80	14	30	14	4
21 *Gammaracanthus lacustris* (Sars)	336	567	4	—	—	—
22 *Pontoporeia affinis* Lindstr.	72	88	5	42	—	1
23 *Astacus astacus* (L.)	308	208	5	—	—	—
24 Acari	60	79	8	—	—	—
25 Ephemeroptera	215	305	6	—	—	—
26 *Ephemera vulgata* (L.)	39	20	6	35	18	4
27 Odonata	56	40	3	—	—	—
28 *Sialis* spp.	33	25	3	—	—	—
29 Trichoptera	66	64	9	45	38	2
30 Dytiscidae	439	187	2	—	—	—
31 Chironomidae, miscell.	170	240	13	39	29	7
32 *Chironomus plumosus* (L.)	24	30	6	34	35	4
33 Chironomini	249	424	9	25	30	3
34 Tanypodinae	94	138	15	36	—	1
35 *Chaoborus flavicans* Meig.	47	61	8	70	21	5
36 Ceratopogonidae	25	—	1	—	—	—
37 Tabanidae	113	153	2	—	—	—
38 Miscellaneous	47	11	2	—	—	—
Total material	79	154	284	29	21	114

Σ DDT				
Mean	S.D.	n	Food	Depth
1	1	6	He	Li
5	4	64	He	Li
—	—	—	He	Li
—	—	—	He	Li
1	1	2	He	Li + Pr
—	—	—	He	Li
—	—	—	He	Li
—	—	—	He	Li
—	—	—	He	Li
8	—	1	He	Li
—	—	—	He	Li
—	—	—	He	Li
—	—	—	He	Li + Pr
—	—	—	He	Li + Pr
4	4	2	Pd	Li
14	9	4	Pd	Pr
11	6	2	Pd	Pr
16	8	2	Pd	Pr
—	—	—	He	Li
15	8	4	Pd	Pr
—	—	—	Pd	Pr
23	—	1	He	Pr
—	—	—	He	Li
—	—	—	Pd	Li + Pr
—	—	—	He	Li
17	6	4	He	Li
—	—	—	Pd	Li
—	—	—	Pd	Li
21	23	2	He	Li
—	—	—	Pd	Li
15	9	7	He	Li + Pr
10	6	4	He	Li
16	19	3	He	Li + Pr
23	—	1	Pd	Li + Pr
16	12	5	Pd	Pr
—	—	—	Pd	Li
—	—	—	Pd	Li
—	—	—	He	Li + Pr
8	8	114		

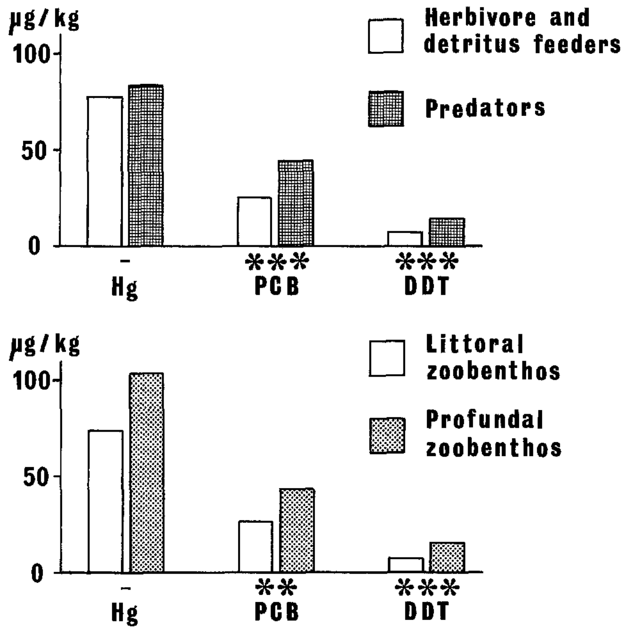

Fig. 2. The average amounts of total mercury (Hg), PCB and Σ DDT, ng/g, wet weight basis, in the herbivore or detritus feeders and in the predatory zoobenthos (above), and in the littoral and profundal zoobenthos (below). The asterisks indicate the differences between the groups according to t-tests: two asterisks = $p < 1\%$, three asterisks = $p < 0.1\%$.

profundal animals. According to the t-test, the difference was significant with a risk $p < 5\%$. Whatever the reasons, a notable difference was observed between the amounts of mercury and chlorinated hydrocarbons in the bathymetric distribution.

Bioaccumulation within Separate Species

Eighty-eight analyses of mercury and 64 of chlorinated hydrocarbons of *Anodonta piscinalis* of various sizes were made. The dependence of the concentrations on the shell-free fresh weight of the individuals was studied. The statistical tests were conducted separately for the mussels of each subarea by calculating the regression equation for the dependence of concentration on the weight and by testing the significance of the coefficients. The dependence of the quantities of PCB and Σ DDT on the animals' weight was not significant, and in most cases the amounts of chlorinated hydrocarbons seemed to be the smaller the greater the size of the animal. All the coefficients of mercury were positive, but for a population sampled from the station 5 only a significance level of $p < 5\%$ was noted. This material of 6 individuals was sampled by scuba diving from a comparative hard bottom, where the mussels seemed to have grown very slowly.

A population of *Mysis relicta* could be divided into two groups on the basis of their size and age. The t-tests between the groups showed that the mercury contents in the larger individuals were higher than in the smaller ones with a risk $p < 5\%$.

Correlations

Correlation coefficients between the amounts of the residues as well as between the residues and fat contents were determined for the animal groups, as shown in Table 4, and for *Anodonta,* relict crustaceans, and other animals. The following correlation coefficients were determined: mercury/fat, mercury/PCB, mercury/Σ DDT, PCB/fat, PCB/Σ DDT, Σ DDT/fat. No significant correlations were found between mercury and fat, mercury and PCB, nor between mercury and Σ DDT. A significant ($p < 5\%$) positive correlation between PCB/fat was found in the following groups: Ephemeroptera, predatory insects and littoral animals. In *Anodonta,* Pelecypoda, Mollusca, and in the herbivore or detritus feeding animals the correlation was negative with the same risk level. A significant positive correlation between Σ DDT/fat was found in Ephemeroptera and a negative one in the predatory insects. Significant correlations were positive between PCB/Σ DDT, and the risk level of significance was $p < 0.1\%$. There was a positive correlation in most of the zoobenthos groups tested.

The amounts of mercury in the zoobenthos material did not correlate with either the amounts of chlorinated hydrocarbons or fat contents. The fat-soluble chlorinated hydrocarbons correlated in some cases with the fat content, but both

Table 4. Average amounts of total mercury, PCB and Σ DDT, ng/g, wet weight basis, in the different taxonomical or ecological groups of zoobenthos of Lake Päijänne. The numbers in parentheses indicate the codes of taxons presented in Table 3. S.D. = standard deviation.

	Total mercury			PCB			Σ DDT		
	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n
Pelecypoda (2–5)	48	48	107	24	16	66	5	4	66
Sphaeridae (3–5)	18	24	19	7	2	2	1	1	2
Gastropoda (6–12)	20	21	23	15	—	1	8	—	1
Mollusca (2–12)	43	45	130	24	16	67	5	4	67
Oligochaeta (13–14)	56	62	6	—	—	—	—	—	—
Mysis relicta (16–18)	43	26	13	35	17	8	14	7	8
Crustacea (16–23)	104	202	46	34	15	13	15	7	13
Insecta (25–37)	119	211	83	42	28	26	16	11	26
Ephemeroptera (25–26)	127	225	12	35	18	4	17	6	4
Chironomidae (31–34)	140	250	43	35	28	15	14	10	15
Herbivore or detritus Feeding Insecta (25, 26, 29, 31–33)	137	249	49	36	27	20	15	11	20
Predatory Insecta (27, 28, 30, 34–37)	94	139	34	64	23	6	17	11	6
Herbivores or detritus feeders	77	150	210	25	19	94	7	8	94
Predatory animals	83	167	74	44	22	20	14	8	20
Zoobenthos—littoral	73	140	230	26	20	95	7	8	95
Zoobenthos—profundal	103	203	54	43	23	19	15	8	19

positive and negative correlations were found and the significance level was low. However, a definite correlation was noted between PCB and Σ DDT.

The correlation coefficients do not reveal any causal connections; however, they may provide a basis for some conclusions. The positive correlation between PCB and Σ DDT may indicate that the residues are of the same origin, food chain transfer and/or behavioural metabolism are similar. PCB and DDT seem to behave in the same way, with the difference that the amounts of PCB are, on an average, 3 to 4 times greater than those of Σ DDT. There are also correlations between the amounts of chlorinated hydrocarbons and fat content. Although this dependence is somewhat weak, it is more apparent than the dependence between mercury and fat content of the materials.

Discussion

Comparison of Levels with Other Investigations

There are fewer studies on the environmental contaminants in the zoobenthos of freshwaters than on the marine invertebrates or on fish. The average quantity of mercury in the zoobenthos of Lake Päijänne (79 ng/g) was approximately the same as the quantities found in the comparatively clean freshwater areas of Sweden (Johnels *et al.* 1967) and France (Cumont and Montiel 1972). Not so smaller quantities of Hg were found in Lake Päijänne than in the mercury polluted areas in Sweden. According to Johnels *et al.* (1967) and Olsson *et al.* (1973), the values in Sweden were as high as 2700 to 17000 ng/g on the wet weight basis. Nuorteva *et al.* (1975) found high mercury values in *Bithynia, Ephemera,* and *Asellus*. Matida and Kumada (1969) found a maximum of 45000 ng/g Hg (dry weight basis) in the freshwater aquatic insects which may correspond to the wet weight values of about ⅓–⅛. Notable quantities of Hg were found, in the brackish-water or in the marine biotopes, especially near the industrial plants producing vinyl chloride. In shellfish, the amounts found were 11000–40000 ng/g (Kurland *et al.* 1960), and in arthropods, near the plant producing acetaldehyde 39000–100000 ng/g, dry weight basis, (Matida and Kumada 1969). Quantities of mercury, lower than those found in Lake Päijänne, were found in the marine or in the brackish biotopes by Günther *et al.* (1972) and Nuorteva and Häsänen (1975).

There are few studies on the quantities of PCB in the freshwater zoobenthos. In Sweden, Södergren *et al.* (1972) found 2 to 12 ng/g in *Gammarus pulex* and 12 ng/g in *Ephemera danica,* wet weight values. The quantities of PCB found in *E. danica* were smaller than those found in *E. vulgata* in Lake Päijänne (average 35 ng/g). Veith *et al.* (1977) found in *Mysis relicta* in Lake Superior 50–120 ng/g of PCB which was much more than the corresponding average of 33 ng/g found in Lake Päijänne. Greichus *et al.* (1977) found in the zoobenthos of a South African reservoir 1800 to 2000 ng/g of PCB on the dry weight basis. Numerous marine studies have been carried out: The quantities of PCB found in mussels (mostly *Mytilus edulis* L.) were 4 to 237 ng/g, wet weight basis, in shrimps 6 to 2500, and in crabs 17 to 7000 ng/g (Duke *et al.* 1970, Giam *et al.* 1972, Butler 1973, Tenberge and Hillebrand 1974, Bagge 1975). Some of these amounts are higher than those of Lake Päijänne. This may be due to the fact that in the surroundings of Lake Päijänne there are no industrial plants producing PCB or using it in their production.

The quantities of Σ DDT in the zoobenthos of Päijänne were smaller than those in the freshwater presented by Hannon *et al.* (1970). Veith *et al.* (1977) found 40 to 53 ng/g of Σ DDT in *Mysis* of Lake Superior, which differs from the amounts found in Lake Päijänne. In marine areas, much greater quantities were noted near the plantations, for which this pesticide was used (Giam *et al.* 1972 Butler 1973, Keiser *et al.* 1973). Also, on the coast of Ireland (Eades and Crowley 1970) and in the Baltic (Bagge 1975) the quantities were somewhat higher. In shrimps and mussels in the North Sea (Tenberge and Hillebrand 1974) and in mussels in Norway (Bjerk and Sundby 1970) the quantities of Σ DDT were about the same as those in Lake Päijänne.

On the coast of Finland (Voipio *et al.* 1977), the amounts of mercury in *Macoma baltica* and *Mesidotea entomon* were, on the average, lower than in the zoobenthos of Lake Päijänne. The amounts of PCB were somewhat greater and those of Σ DDT remarkably greater than the corresponding mean values in Lake Päijänne (Hg 66, PCB 59 and Σ DDT 39 ng/g wet weight).

Conclusions

On the basis of this study a slight annual increase was noted in the quantities of PCB and Σ DDT in Lake Päijänne. The reason for this increase must be in the atmospheric transportation of the chemicals, because the use of PCB and Σ DDT in Finland has decreased or completely eliminated. However, a three-year sampling period may not be long enough to study temporal changes, and in addition to annual variations there are other factors which make the finding of the changes difficult.

The quantities of mercury may have decreased after the usage was halted, and the regional distribution of mercury may be affected by its accumulation in the food chain and it may be greater in the oligotrophic parts of the lake than in its former sources (Särkkä *et al.* 1978).

Some differences between the separate taxons were found, and chlorinated hydrocarbons accumulated in the predatory species more so than mercury, which accumulated in *Mysis*. The bathymetric distribution of chlorinated hydrocarbons and mercury was different, which may be partly due to the differences in the taxonomical composition. Vertical differences in temperature and currents may also have an effect: a low temperature and weak movement of water in the profundal depths probably retard movement of the residues from the ecosystem. On the other hand, the stability and transformation of mercury are dependent on several environmental factors (e.g. Fagerström and Jernelöv 1972, Jernelöv *et al.* 1975) which can be remarkably different in littoral and profundal depths.

If regional or annual differences are being sought, a problem to be considered is, what species or taxons should be sampled. A taxon most suitable to indicate the grade of contamination preferably would be one species and not a genus, family or a larger taxonomical unit. It must be abundant enough, easy to sample, and its contents should be high, if differences between taxons are seen. In Lake Päijänne there are the following abundant species which are easy to sample with suitable methods: *Spongilla lacustris, Anodonta piscinalis, Mysis relicta, Pallasea quadrispinosa, Chironomus plumosus* and *Chaoborus flavicans*. *Anodonta* and *Spongilla* live in many subareas, with regard to eutrophication and pollution, whereas *Mysis, Ephemeroptera* and particularly *Pallasea* avoid living in the most polluted areas. *Chironomus plumosus* is abundant in the eutrophicated areas only. Larvae of *Chaoborus* are present in the whole lake but the species is abundant in polluted areas only (Särkkä in prep.). *Anodonta* and *Spongilla* could thus be recommended as indicators or monitory organisms. The sampling of *Anodonta* and *Spongilla* is easy by scuba diving, sufficient biomasses (several grams) of them might be sampled faster than the other species mentioned.

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References

Ahling, B., and S. Jensen: Reversed liquid partition in determination of polychlorinated biphenyl (PCB) and chlorinated pesticides in water. Anal. Chem. **42**, 1483 (1970).

Bagge, P.: Pesticide residues in some Baltic animals—a review of selected literature. Pure and Applied Chem. **42**, 129 (1975).

Bjerk, J. E., and R. Sundby: Rester av klorinsekticider og polyklorerte bifenyler i testorganismer fra jord og vann. Norsk Veterinaer Tidskr. **82**, 241 (1970).

Butler, P. A.: Organochlorine residues in estuarine mollusks, 1965–72 national pesticides monitoring program. Pestic. Monit. J. **6**, 238 (1973).

Cumont, G., and A. Montiel: Etude de l'accumulation du mercure dans un écosystème aquatique. Tribune de Cebedeau 1972 (**26**) (352), 124 (1972).

Duke, T. W., I. I. Lowe, and A. J. Wilson: A polychlorinated biphenyl (Aroclor 1254) in the water, sediment, and biota of Escambia Bay, Florida. Bull. Environ. Contam. Toxicol. **5**, 171 (1970).

Eades, J. F., and M. Crowley: Pesticide residue levels in mussels in Irish coastal waters. International Council for the Exploration of the Sea. C. M. 1970 E. Fisheries Improvement Committee. Ref.: Shellfish and Benthos Cttee, 1 (1970).

Fagerström, T., and A. Jernelöv: Some aspects of the quantitative ecology of mercury. Water Res. **6**, 1193 (1972).

Giam, C. S., A. R. Hanks, R. L. Richardson, W. M. Sackett, and M. K. Wong: DDT, DDE and polychlorinated biphenyls in biota from the Gulf of Mexico and Caribbean Sea—1971. Pestic. Monit. J. **6**, 139 (1972).

Greichus, Y. A., A. Greichus, B. D. Amman, D. J. Call, D. C. D. Hamman, and R. M. Pott: Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. I. Hartbeesport Dam. Transvaal and Voëlvlei Dam, Cape Province, Republic of South Africa. Arch. Environ. Contamin. Toxicol. **6**, 371 (1977).

Günther, F., I. Oostinga, and O. Burckhardt: Über Quecksilbergehalte in See- und Süsswasserfischen sowie in Krusten-, Muschel- und Säugetieren der ostfriesischen Küsten- und Binnengewässer. Med. u. Ernähr. **13**, 263 (1972).

Hannon, M. R., Y. A., Greichus, R. L. Applegate, and A. C. Fox: Ecological distribution of pesticides in Lake Poinsett, South Dakota. Trans. Amer. Fish. Soc. **99**, 496 (1970).

Häsänen, E.: Vesistöjen elohopeapitoisuudesta ja sen tutkimisesta. (Summary: Mercury content of water and its investigation). Limnologisymposion **1969**, 33 (1973).

Hatch, W. R. and W. L. Ott: Determination of submicrogram quantities of mercury by atomic absorption spectrophotometry. Anal. Chem. **40**, 2085 (1968).

Hattula, M. L.: Analysis of DDT- and PCB-type compounds at low level in fish with reference to pike, perch and bream in Lake Päijänne. Univ. Helsinki, EKT Ser. **301**, 1 (1973).

Jernelöv, A. and H. Lann: Mercury accumulation in food chains. Oikos **22**, 403 (1971).

Jernelöv, A., L. Landner and T. Larsson: Swedish perspectives on mercury pollution. J. Water Pollut. Contr. Fed. **47**, 810 (1975).

Johnels, A. G., T. Westermark, W. Berg, P. I. Persson, and B. Sjöstrand: Pike (Esox lucius L.) and some other aquatic organisms in Sweden as indicators of mercury contamination in the environment. Oikos **18**, 323 (1967).

Keiser, R. K., J. A. Amado, and R. Murillo: Pesticide levels in estuarine and marine fish and invertebrates from the Guatemalan Pacific coast. Bull. Mar. Sci. **23**, 905 (1973).

Kurland, L. T., S. N. Foar, and H. Seidler: Minamata disease. World Neurol. **1**, 370 (1960).

Markkula, M.: Sales of pesticides in Finland 1971. Kemian Teollisuus **29**, 534 (1972).

Matida, Y., and H. Kumada: Distribution of mercury in water, bottom mud and aquatic organisms of Minamata Bay, the river Agano and other water bodies in Japan. Bull. Freshwater Fish. Res. Lab. **19**, 73 (1969).

Nuorteva, P., and E. Häsänen: Bioaccumulation of mercury in Myoxocephalus quadricornis (L.) (Teleostei, Cottidae) in an unpolluted area of the Baltic. Ann. Zool. Fennici **12**, 247 (1975).

Nuorteva, P., E. Häsänen, and S- L. Nuorteva: Lääkintöhallituksen elohopeasuositusten teho Hämeenkyrössä suoritettujen tutkimusten valossa. (Summary: The effectiveness of the Finnish antimercury measurements in the moderately polluted area of Hämeenkyrö). Ympäristö ja Terveys **6**, 611 (1975).

Olsson, M., A. G. Johnels, and T. Westermark: Kvicksilverhalter i biologiskt material från Mörrumsån. IVL-konferensen **1972**, 1 (1973).

Paasivirta, J., M. L. Hattula, and J. Särkkä: Päijänteen ravintoketjujen myrkkyjäämätutkimus. Jyväskylä, Univ. Jyväskylä (1975).

Rautapää, J.: The use of PCB compounds in Finland. Kemian Teollisuus **29**, 526 (1972).

Rosenberg, D. M.: Food chain concentration of chlorinated hydrocarbons pesticides in invertebrate communities: a re-evaluation. Quaest. Ent. **11**, 97 (1975).

Särkkä, J., M. L. Hattula, J. Paasivirta, and J. Janatuinen: Mercury and chlorinated hydrocarbons in food chain of Lake Päijänne, Finland. Holarctic Ecol. (in print, 1978).

Särkkä, J.: Zoobenthos of Lake Päijänne and its relations to some environmental factors. Acta Zool. Fenn. (in prep., 1978).

Siegel, S.: Nonparametric statistics for the behavioral sciences. New York, Toronto, London: McGraw-Hill (1956).

Södergren, A., B. Svensson, and S. Ulfstrand: DDT and PCB in south Swedish streams. Environ. Pollut. **3**, 25 (1972).

Tenberge, W. F., and M. Hillebrand: Organochlorine compounds in several marine organisms from the North Sea and the Dutch Wadden Sea. Netherlands J. of Sea Res. **8**, 361 (1974).

Veith, G. D., D. W. Kuehl, F. A. Puglisi, G. E. Glass, and J. G. Eaton: Residues of PCB's and DDT in the western Lake Superior ecosystem. Arch. Environ. Contamin. Toxicol. **5**, 487 (1977).

Voipio, A., K. Erkomaa, E. Karppanen, I. Mäkinen and V. Tervo: Eräiden raskaiden metallien ja orgaanoklooriyhdisteiden pitoisuudet Itämeren kaloissa ja pohjaeläimissä. Ympäristö ja Terveys **8**, 127 (1977).

Westöö, G., and K. Noren: Determination of organochlorine pesticides and polychlorinated biphenyls in animal foods. Acta Chem. Scand. **24**, 1639 (1970).

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